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# Studies of $K_S^0$ decays with the KLOE detector at DAΦNE

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**Abstract**

The KLOE detector at DAΦNE , the Frascati $\phi$-factory, has collected about 30 pb$^{-1}$ by the end of year 2000. The $\phi(1020)$ meson decays about 34% of the times into a $K_L^0$-$K_S^0$ pair; DAΦNE is therefore an exceptional source of almost monochromatic, tagged $K_S^0$ particles, allowing for detailed studies of their more rare decays. The above mentioned integrated luminosity corresponds to about 30 millions produced $K_S^0$.

In KLOE the presence of a $K_S^0$ is easily tagged by the observation of the corresponding $K_L^0$ impinging onto the electromagnetic calorimeter before decay. Thanks to this technique we have performed a preliminary measurement of the ratio of the partial decay widths of the $K_S^0$ into two charged and two neutral pions: $\mathbf{B(K_S^0 \rightarrow \pi^+\pi^-)/B(K_S^0 \rightarrow \pi^0\pi^0)} = 2.23 \times (1 \pm 0.35\times 10^{-2}$ (stat) $\pm\ 1.5\times 10^{-2}$ (syst) ).

We have also observed several hundreths semileptonic decays of the $K_S^0$ by far the largest sample of this decay mode ever observed by any experiment so far. The preliminary estimate of the corresponding branching ratio is $\mathbf{B(K_S^0 \rightarrow \pi^\pm e^\mp \nu)} = (6.8 \pm 0.3$ (stat)$)\times 10^{-4}$; systematic effects are still under study and are presently estimated to be at the few percent level.

# 1 INTRODUCTION

The KLOE detector at DAΦNE , the Frascati $\phi$-factory, has started physics data taking in April 1999. It has collected about 30 pb$^{-1}$ by the end of year 2000.

The $\phi(1020)$ meson decays $\sim$ 34% of the times into a $K_L^0$-$K_S^0$ pair; at peak energy, about 1 million of such decays occur every delivered pb$^{-1}$. DAΦNE is therefore an exceptional source of almost monochromatic, tagged $K_S^0$ particles, allowing for detailed studies of their more rare decays.

In the present paper, the status of the analysis about two different $K_S^0$ decay channels is presented.

Firstly, a measurement of the ratio among the branching ratios into two charged and neutral pions is presented. This is relevant for CP violation studies, since it enters the double ratio from which $\mathrm{Re}(\epsilon'/\epsilon)$ is derived. Moreover it is of interest for chiral perturbation theory studies, especially if the radiation of soft photons in the charged decay is properly taken into account.

Secondly, a measurement of the branching ratio of the decay $K_S^0 \rightarrow \pi^\pm e^\mp \nu$ is presented. Up to now, only one measurement of this branching

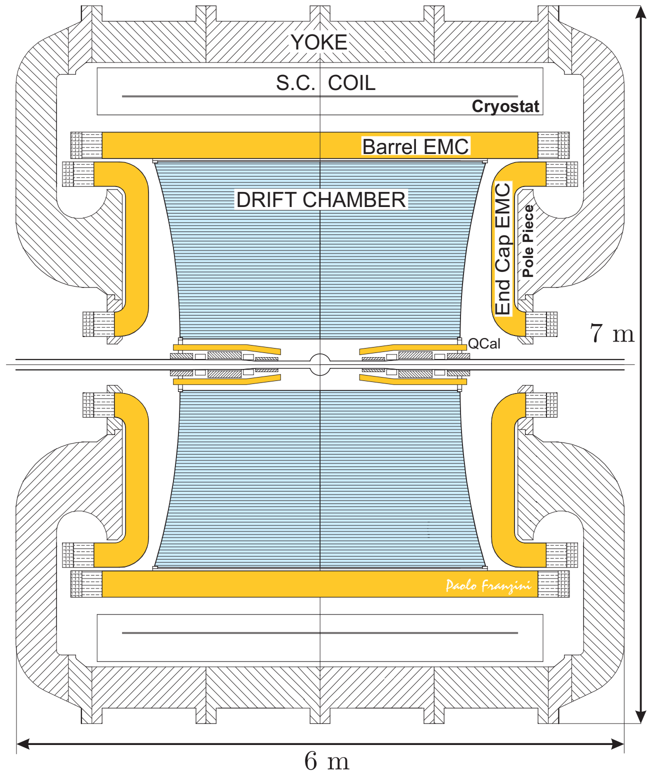


Figure 1: Side view of the KLOE detector.

ratio exists, based on a data sample of 75 events [1]. In the present analysis the measurement is performed using a sample of about 600 event candidates with a background contamination of less than 10%.

## 2 THE KLOE DETECTOR

The KLOE (KLOngExperiment) detector [2], designed with the primary goal of measuring $\epsilon'/\epsilon$ with a sensitivity of the order of one part in ten thousand, is also particularly well suited to perform studies on all charged and neutral decays of the $K^0_S$ meson.

It consists of a large tracking chamber, a hermetic electromagnetic calorimeter and a large magnet surrounding the whole detector, consisting of a superconducting coil and an iron yoke (see figure 1).

The tracking chamber [4, 5] (DC) is a cylindrical, 2 m radius, 3.3 m long drift chamber. The total number of wires is 52140, out of which 12582 are the sense ones. It operates with a low-Z, He gas mixture, to minimize

multiple scattering of charged particles and regeneration of $K_L^0$'s. The 58 concentric layers of wires are strung in an all-stereo geometry, with constant inward radial displacement at the chamber center. A spatial resolution better than 200 $\mu$m is obtained. The momentum resolution for 510 MeV/c electrons and positrons is 1.3 MeV/c, in the angular range $130^\circ > \theta > 50^\circ$.

The electromagnetic calorimeter[3, 6] (EmC) is a lead scintillating fibers sampling calorimeter, divided into a barrel section and two endcaps. The modules of both sections are read out at the two ends by a total of 4880 photomultipliers. In order to minimize dead zones in the overlap region between barrel and endcaps, the modules of the latter are bent outwards with respect to the decay region.

The calorimeter was designed to detect with very high efficiency photons with energy as low as 20 MeV, and to accurately measure their energy and time of flight. Absolute calibrations of energy and time scales are performed using collision data. An energy resolution of $5.7\%/\sqrt{E(GeV)}$ is achieved throughout the whole calorimeter together with a linearity in energy response better than 1% above 80 MeV and 4% between 20 to 80 MeV.

Moreover, $\gamma$ samples from different processes are selected to measure the time resolution at various energies; it scales according to the law $\sigma_t$=$(54/\sqrt{(}E(GeV)\oplus$ 147) ps, where the first term is in agreement with test beam data, while the second, to be added in quadrature, is dominated by the intrinsic time spread due to the bunch length.

# 3 STUDIES ON PHYSICS CHANNELS

## 3.1 Tagging of $K_S^0$ decays

When a $\phi$ meson decays into two neutral kaons $C$-parity invariance forces the two kaons to be in a $K_S^0$-$K_L^0$ state. The observation of a $K_S^0$, therefore, *tags* the presence of the $K_L^0$ in the opposite hemisphere. Similarly, $K_S^0$ decays can be selected by observing the $K_L^0$ on the other side.

As $K_S^0$ tagging strategy, one can either look for a charged vertex well inside the DC volume, or identify a EmC cluster compatible with being due to a slowly moving ($\beta \approx 0.22$) neutral particle (so called 'KCRASH' event). Actually, more than one half of the $K_L^0$'s reach the calorimeter before they decay. For the above reason the 'KCRASH' tag provides a particularly clean, high statistics $K_S^0$ sample.

More specifically, events are selected on the basis of the two following requests:

1. The presence of a EmC cluster with energy larger than 50 MeV, and transverse radius larger than 60 cm, due to the $K_S^0$ decay; it is needed to determine the $t_0$ of the event, i.e. the time at which the $\phi$ production and decay occurred.
2. The presence of a EmC cluster in the barrel region with energy larger than 100 MeV and time compatible with being due to a particle moving at a velocity in the $\phi$ rest frame $0.195 < \beta^* < 0.2475$ (the KCRASH).

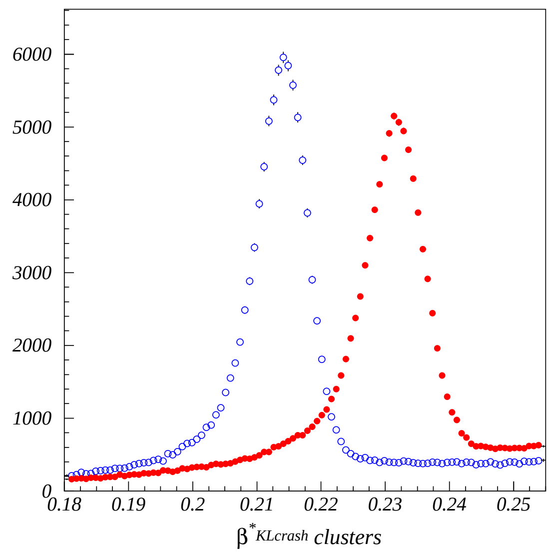


Figure 2: $\beta^*$ distributions for KCRASH clusters when the accompanying $K_S^0$ decays into two charged (open circles) or neutral (black circles) pions.

The tag efficiency is slightly dependent on the $K_S^0$ decay type, since the time zero estimate (first point above) is determined by particles with different velocities (prompt photons in the case of $K_S^0 \to \pi^0\pi^0$ events, pions in $K_S^0 \to \pi^+\pi^-$ ones, pions or electrons for semileptonic decays). For instance, the distributions for the reconstructed $\beta^*$ for charged and neutral two pions decays are shown in figure 2; it turns out that the ratio of the efficiencies for having a KCRASH in the above mentioned velocity interval is $\epsilon^{+-}/\epsilon^{00} = (95.030 \pm 0.005)\%$, where the error is statistical only.

In the following, all events are tagged making use of the KCRASH prescription.

### 3.2 $K_S^0 \to \pi^+\pi^-$ and $K_S^0 \to \pi^0\pi^0$ decays

The $K_S^0$ decays into two neutral pions are selected requiring the presence of four EmC clusters with a timing compatible with the hypothesis of being due to prompt photons (within 5 $\sigma$'s), and energy larger than 20 MeV. The prompt clusters distribution for the data taken during summer 2000 is shown in figure 3 together with the Monte Carlo expectation. The distribution agree well between each other. The energy spectrum and the angular distribution for the photons of the events with four prompt clusters are shown in figure 4. Again, good agreement between data and Monte Carlo is observed.

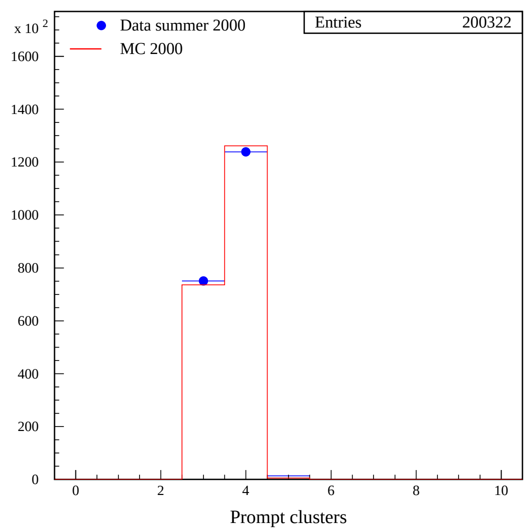


Figure 3: Distribution of the number of prompt clusters, $N_\gamma$ found in KCRASH events for data (black points) and Monte Carlo (dashed line). The request $N_\gamma >$ 2 is applied, to reject machine background events.

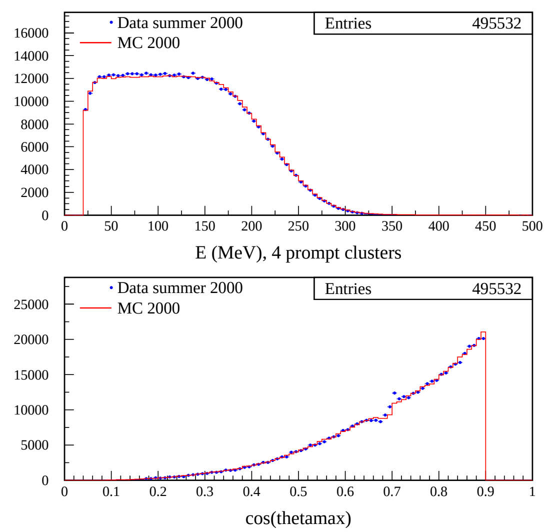


Figure 4: Energy (upper plot) and angular (lower plot) distributions of the photons in four $\gamma$ events. Points are data, solid line is the Monte Carlo prediction for $K_S^0 \to \pi^0\pi^0$ events.

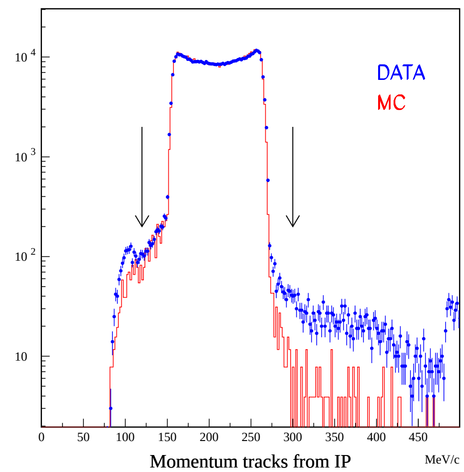


Figure 5: Momentum distribution for the tracks originating from the I.P. in KCRASH selected events. Black points are data, while the solid histogram is the Monte Carlo expectation for $K_S^0 \to \pi^+\pi^-$ events. Tracks with P$>$ 300 MeV/c are mostly due to machine background, while the peak at P$\sim$ 100 MeV/c is due to the residual contamination from $\phi \to K^+K^-$ events.

Photon detection efficiency is estimated by real data using $\gamma$'s in the decays $\phi \to \pi^+\pi^-\pi^0$ as a control sample. The final selection efficiency for the $K_S^0 \to \pi^0\pi^0$ decay channel is $\epsilon_{00}$=(56.7$\pm$0.1)%, dominated by acceptance.

The selection of $K_S^0 \to \pi^+\pi^-$ events proceeds through the request of two oppositely charged tracks with polar angle in the interval $30^\circ < \theta < 150^\circ$, originating in a cylinder of 4 cm radius and 10 cm length around the interaction point. A further request is applied on the measured momenta to remove the residual background due to charged kaon decays: $120 <$ p(MeV/c) $< 300$ (see figure 5). Both tracks are also required to impinge to the calorimeter, in order to enhance the probability for having a good $t_0$ determination.

The track reconstruction efficiency is measured in momentum and polar angle bins from data subsamples. The final selection efficiency is $\epsilon_{+-}$=(58.5$\pm$0.1)%, again dominated by acceptance.

The trigger efficiency is determined with real data for both decay types. It is (99.69 $\pm$ 0.03)% for the neutral decay and (96.5 $\pm$ 0.1)% for the charged one. The above figure includes also the probability for having at

least one good cluster to determine the $t_0$ of the event, as explained in the previous paragraph.

Background levels are kept well below 1% for both decay types.

Using part of the data acquired in year 2000, corresponding to ∼10 $pb^{-1}$, 872748 $K^0_S \to \pi^+\pi^-$ and 414118 $K^0_S \to \pi^0\pi^0$ decays have been selected, providing: $\mathbf{B(K^0_S \to \pi^+\pi^-)/B(K^0_S \to \pi^0\pi^0)} = 2.23 \times (1 \pm 0.35\times 10^{-2}$ (stat) $\pm\, 1.5\times 10^{-2}$ (syst) )

to be compared with the present PDG value [10] $2.197 \times (1 \pm 1.2\times 10^{-2}$ (stat) $\pm\, 1.5\times 10^{-2}$ (syst) ).

Systematics are dominated by residual uncertainties in photon counting and in the understanding of the difference between the tagging efficiencies for the two channels. More precise studies are presently under way.

### 3.3 $\mathbf{K^0_S \to \pi^\pm e^\mp \nu}$ decays

In order to search for $K^0_S \to \pi^\pm e^\mp \nu$ decay candidates, events with a KCRASH and two oppositely charged tracks from the interaction region are initially selected. Events are then rejected if the two tracks invariant mass (in the pion hypothesis) and the resulting $K^0_S$ momentum in the $\phi$ rest frame are compatible with those expected for a $K^0_S \to \pi^+\pi^-$ decay. According to Monte Carlo, this preselection has an efficiency, after the tag, of ∼ 62.4% on the signal.

In order to perform a time of flight identification of the charged particles, both tracks are required to be associated with a EmC cluster. The acceptance for such request, estimated by Monte Carlo, is (51.1 ± 0.2) %. The time of flight difference $\Delta\delta$t for the two charged particles in both e-$\pi$ and $\pi$-$\pi$ hypotheses is then computed; events are accepted if $|\Delta\delta t(\pi\text{-}\pi)| > 1.5$ ns and $|\Delta\delta t(\pi\text{-}e)| < 1$ ns and $|\Delta\delta t(e\text{-}\pi)| > 3$ ns. The efficiency on the signal, estimated by means of $K^0_L$'s decaying into $\pi e \nu$ before the DC internal wall, is (82.0±0.7)% .

Also the trigger efficiency as well as the one for correctly associating a track to a cluster and for having a good $t_0$ determination is measured directly on data, making use of $K^0_L \to \pi^\pm e^\mp \nu$, $\phi \to \pi^+\pi^-\pi^0$ and $K^0_S \to \pi^+\pi^-$subsamples. The product of these efficiencies turns out to be (81.7 ± 0.5) %.

The event is finally kinematically closed. The $K^0_S$ momentum is estimated making use of the measured direction of the $K^0_L$ and of the $\phi$ 4-momentum. The missing energy and momentum of the $K^0_S$ -$\pi$-e system, corresponding to the neutrino's ones, are then computed. Their difference is distributed as in figure 6; it must be equal zero for the signal. Data are fit using MC spectra for both signal and the residual background, due mostly to $K^0_S \to \pi^+\pi^-$ events with an early decay of one of the two pions.

Using data corresponding to a luminosity of ∼ 17 $pb^{-1}$, the measured yield is $N(K^0_S \to \pi^\pm e^\mp \nu) = 627 \pm 30$ events, for a total efficieny of (21.8 ± 0.3) %. The total number of events is then normalised to the amount of observed $K^0_S \to \pi^+\pi^-$ events, to give $\mathbf{B(K^0_S \to \pi^\pm e^\mp \nu)} = (6.8 \pm 0.3$ (stat)$)\times 10^{-4}$. In the ratio, the tagging efficiency, which is the largest cause of systematic uncertainty, cancels out identically. Other systematic

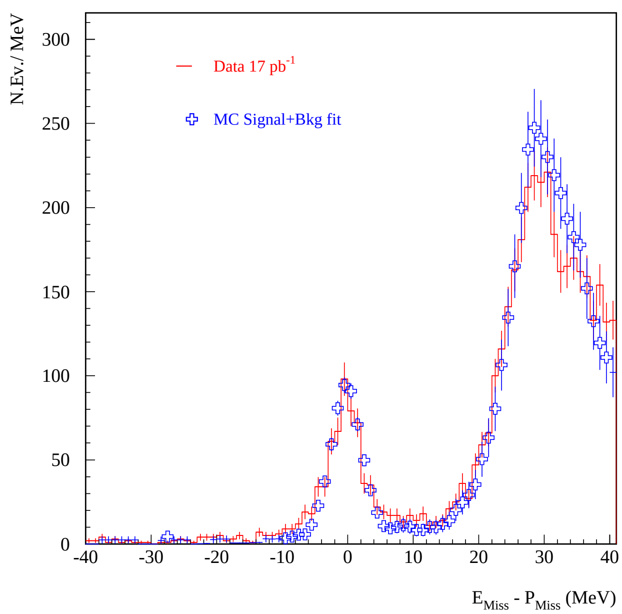


Figure 6: Distribution of the difference between missing energy and missing momentum for $K^0_S \to \pi^{\pm} e^{\mp} \nu$ candidates. The peak at zero is the signal. The distribution is fit to the Monte Carlo of signal and background in the range -40 MeV + 40 MeV.

effects, presently under study, are preliminarly estimated to be at a few percent level.

This result can be compared with the one obtained by the CMD2 Collaboration[1]: B($K_S^0 \rightarrow \pi^{\pm} e^{\mp} \nu$) = $(7.2 \pm 1.2) \times 10^{-4}$, and with the prediction obtained assuming $\Gamma_S = \Gamma_L$ : B($K_S^0 \rightarrow \pi^{\pm} e^{\mp} \nu$) = $(6.70 \pm 0.07) \times 10^{-4}$.

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